CLAIMS

What is claimed is:

1. A method of motion capture comprising the steps of:

providing an energy source (73); said energy source (73) disposed on a subject (12) at a location to be tracked; said subject (12) moving from position-to-position within a volume of space (16);

emitting a signal (40) from said energy source (73);

providing a plurality of widely-spaced receiving antennas (76, 78) disposed at edges of said volume of space (16);

measuring a phase difference ($\Delta\phi_1$) of said signal (40) being received at each independent pair of said plurality of receiving antennas (76, 78) when said energy source (73) is at a first position (72);

changing a physical position of said energy source (73) from a first position (72) to a second position (74);

measuring a phase difference ($\Delta\phi_2$) of said signal (40) being received at each said independent pair of said plurality of receiving antennas (76, 78) when said energy source (73) is at a second position (74); and

estimating a change in said physical position of said energy source (73) by comparing measured phase differences ($\Delta\phi_1$, $\Delta\phi_2$) of received said signal (40) at each said independent pair of said plurality of receiving antennas (76, 78).

2. The method as claimed in Claim 1, in which the step of providing an energy source (73) disposed on a subject (12) includes the step of providing a low-power radio frequency transmitter (30) coupled to a marker antenna (14) on said subject (12).

3. The method as claimed in Claim 1, in which the step of estimating a change in said physical position (72, 74) of said energy source (73) by comparing measured phase differences ($\Delta\phi$) of received said signal (40) at each one of said plurality of receiving antennas (76, 78) further includes the steps of:

measuring a signal phase (ϕ) at each one said widely spaced plurality of receiving antennas (76, 78) when said subject body (12) is at a first position;

moving said energy source (73) with said subject body (12) from said first position (72) a distance (82) to said second position (74);

measuring a change of said received signal phase ($\Delta\phi$) at each of said widely spaced plurality of receiving antennas (76, 78) when said energy source is at said second position (74);

estimating the direction of motion and the distance moved 82 by comparing

said measured change of received signal phase ($\Delta\phi$) at said widely-spaced plurality of receiving antennas (76, 78); said received signal phase (ϕ) being dependent only on a signal wave length (λ) and said distance and direction moved (82) by said energy source (73); and

continuing said movement (82) and repeating said signal phase measurements, thereby tracking the direction and motion of said energy source (73) without use of an absolute phase reference.

4. The method as claimed in Claim 1, in which the step of estimating a change in said physical position (72, 74) of said energy source (73) by comparing measured phase differences ($\Delta\phi$) of received said signal (40) at each one of said plurality of receiving antennas (76, 78) further includes the steps of:

measuring a signal phase difference ($\Delta\phi$) of received said signal (40) at each one of said widely spaced plurality of receiving antennas (76, 78);

evaluating all allowable values of a difference of pairs (Δn) of integer values (n_1, n_2) which give the same said measured value of said signal phase difference ($\Delta\phi$);

selecting a set of said values of a difference of pairs (Δn) of integer values (n_1, n_2) for which surfaces of all hyperbolas of revolution which are defined by said difference of pairs (Δn) of integer values (n_1, n_2) intersect at a same point; and

said same point of intersection being said physical position (74) of said energy source (73) at the time of said signal phase difference ($\Delta\phi$) measurement.

5. The method as claimed in Claim 2, in which the step of emitting a signal (40) from said energy source (73) includes emitting a microwave signal (40) from said marker antenna (14).

6. The method as claimed in Claim 4, in which said microwave signal is at a frequency of approximately 2.4 GHz.

7. The method as claimed in Claim 5, in which said plurality of receiving antennas (76, 78) includes at least four receiving antennas.

8. The method as claimed in Claim 6, adapted to mapping of human muscle, joint and bone interactions for performing clinical gait analysis of persons having neuromuscular, musculoskeletal, or neurological impairments.

9. The method as claimed in Claim 6, adapted to mapping and analysis of human body motion for improving performance in sports.

10. The method as claimed in Claim 6, adapted to mapping human body motion for evaluation of human interaction with military equipment.

11. The method as claimed in Claim 6, adapted to tracking body motion of humans and animals for implementing realistic animation in film and television entertainment.

12. The method as claimed in Claim 6, adapted to tracking body motion of humans and animals for implementing realistic animation in computer games and presentations.

13. An apparatus comprising:

an energy source (73); said energy source (73) disposed on a subject (12) at a location to be tracked; said subject (12) moving from position-to-position within a volume of space (16); said energy source (73) emitting a signal (40);

a plurality of widely-spaced receiving antennas (76, 78), each one of said plurality of receiving antennas (76, 78) being disposed at edges of said volume of space (16);

a phase difference ($\Delta\phi_1$), of said emitted signal (40) being measured at each independent pair of said plurality of receiving antennas (76, 78) when said energy source (73) is at a first position (72);
a phase difference ($\Delta\phi_2$), of said emitted signal (40) being measured at said independent pair of said plurality of receiving antennas (76, 78) after moving said energy source (73) from a first position (72) to a second position (74); and

a change (82) in said physical position (72, 74) of said energy source (73) being determined by comparing a change in said measured phase difference

($\Delta\phi_2$-$\Delta\phi_1$) of received said signal (40) at each said independent pair of said plurality of receiving antennas (76, 78).

14. The apparatus as claimed in Claim 13, in which said energy source (73) disposed on a subject (12) includes a low-power radio frequency transmitter (30) coupled to a marker antenna (14).

15. The apparatus as claimed in Claim 13, in which:

the direction of motion and the distance moved (82) by said energy source (73) being dependent only on a signal wave length (λ) and a change of relative phase of the received, propagated signal (40); and

said measurements being repeated as said movement (82) continues, thereby tracking the direction and motion of said energy source (73) without use of an absolute phase reference.

16. The apparatus as claimed in Claim 14, in which said emitted signal (40) from said energy source (73) includes a microwave signal (40) from said marker antenna (14).

17. The apparatus as claimed in Claim 16, in which said microwave signal is at a frequency of approximately 2.5 GHz.

18. The apparatus as claimed in Claim 16, in which said plurality of receiving antennas includes at least four receiving antennas.

19. A method of motion capture comprising the steps of:

providing an energy source (102); disposing said energy source (102) on a subject (12) at a location to be tracked; said subject (12) moving from position-to-position within a volume of space (16);

emitting a signal (40) having a wavelength (λ) from said energy source (102);

providing a plurality of widely-spaced receiving antennas (108, 110) disposed at edges of said volume of space (16);

representing a length (d) of each signal path (104, 106) from said energy source (102) to each one of said plurality of widely-spaced receiving antennas (108, 110) as an integer number (n) of said signal wavelengths (λ) plus a fractional signal wavelength (δ); a difference in signal path length (Δd) to each one of any pair of said plurality of widely-spaced receiving antennas (108, 110) being characterized by a difference of said integer numbers (n_1-n_2) multiplied by said signal wavelength (λ) plus a difference in said fractional signal wavelengths (δ_1-δ_2);

assuming a plurality of values of integer number difference (Δn), a first said integer number difference (Δn_1) being characterized as a first integer value (n_1) less a second integer value (n_2), a second said integer number difference (Δn_2) being characterized as a third integer value (n_3) less a fourth integer

value (n_4) and so on, for each value of integer number difference (Δn) possible within said volume of space (16);

measuring a phase difference ($\Delta\phi$) between each said signal (40) received from said energy source (102) at each said pair of said plurality of receiving antennas (108, 110); each one of said plurality of values of integer number difference (Δn) and each said measured phase difference ($\Delta\phi$) defining a surface of locations (112) upon which said energy source (102) may be located;

selecting one of said plurality of values of integer difference (Δn) for each pair of said plurality of receiving antennas (108, 110) and calculating a potential energy source location (103) having a smallest mean square distance from all of the surfaces of location (112) defined by said selected values of integer difference (Δn) and said measured phase differences ($\Delta\phi$);

iterating said calculations of said potential energy source location using all of said assumed plurality of values of integer difference (Δn) possible within said volume of space (16) and finding each said energy source position (103) until a final absolute energy source position (103) is found at which a smallest said mean square distance from corresponding said surfaces of location (112) exists.

20. The method as claimed in Claim 19, in which the step of providing a plurality of widely-spaced receiving antennas (108, 110) disposed at edges of said volume of space (16), includes providing at least four widely-spaced receiving antennas.

21. An apparatus comprising:

an energy source (102); said energy source (102) disposed on a subject (12) at a position to be tracked; said subject (12) moving from position-to-position within a volume of space (16); said energy source (102) emitting a signal (40) at a wavelength (λ);

a plurality of widely-spaced receiving antennas (108, 110), each one of said plurality of receiving antennas (108, 110) being disposed at an edge of said volume of space (16);

an absolute position (103) of said energy source (102) within said volume of sapace (16) being determined by calculation based on characteristics of received said signal (40) at each one of said plurality of receiving antennas (108, 110), wherein

a length (d) of each signal path (104, 106) from said energy source (102) to each one of said plurality of widely-spaced receiving antennas (108, 110) is represented as an integer number (n) of said signal wavelengths (λ) plus a fractional signal wavelength (δ); a difference in signal path length (Δd) to each one of any pair of said plurality of widely-spaced receiving antennas (108, 110) is characterized by a difference of said integer numbers (n_1-n_2) multiplied by said signal wavelength (λ) plus a difference in said fractional signal wavelengths (δ_1-δ_2);

a plurality of values of integer number difference (Δn) is assumed, a first said integer number difference (Δn_1) being characterized as a first integer value (n_1) less a second integer value (n_2), a second said integer

number difference (Δn_2) being characterized as a third integer value (n_3) less a fourth integer value (n_4) and so on, for each value of integer number difference (Δn) possible within said volume of space (16);

a phase difference ($\Delta\phi$) between each said signal (40) received from said energy source (102) is measured at each said pair of said plurality of receiving antennas (108, 110); each of said plurality of values of integer number difference (Δn) and said each said measured phase difference ($\Delta\phi$) defining a surface of locations (112) upon which said energy source (102) may be located;

one of said plurality of values of integer difference (Δn) is selected for each pair of said plurality of receiving antennas (108, 110);

an energy source location (103) is found having a smallest mean square distance from all of said surfaces of location (112) defined by said selection of a value of integer difference (Δn) and said measured phase difference ($\Delta\phi$); and

computations of said potential energy source locations are iterated using all of said assumed plurality of values of integer difference (Δn) possible within said volume of space (16) and each said energy source position (103) is determined until a final absolute energy source position (103) is found at which a smallest said mean square distance from corresponding said surfaces of location (112) exists.

22. An apparatus comprising:

transmitting means (30) for emitting a radio-frequency (RF) signal (40); said transmitting means (30) being disposed on a subject (12) at a location to be tracked; said subject (12) moving from position-to-position within a volume of space (16);

a plurality of antenna means (76, 78) for receiving said RF signals (40) at a plurality of widely-spaced locations, each one of said plurality of antenna means (76, 78) being disposed at edges of said volume of space (16);

a phase difference ($\Delta\phi_1$) of said emitted signal (40) being measured <u>at</u> each independent pair of said plurality of antenna means (76, 78), said phase difference ($\Delta\phi_1$) depending on a path length (80, 84, 86, 88) from said energy source (73) to a said receiving antenna (76, 78); and

a change (82) in said physical position (72, 74) of said transmitting means (73) being determined by comparing a change in said measured phase difference ($\Delta\phi_2$-$\Delta\phi_1$) of received said signal (40) at each said independent pair of said plurality of antenna means (76, 78).

23. The apparatus as claimed in Claim 22, in which said transmitting means (73) includes a low-power, radio frequency transmitter (30) coupled to a marker antenna (14).

24. The apparatus as claimed in Claim 23, in which said emitted signal (40) from said energy source (73) includes a microwave signal (40) emitted from said marker antenna (14).

25. The apparatus as claimed in Claim 24, in which said microwave signal is at a frequency of approximately 2.5 GHz.

26. The apparatus as claimed in Claim 24, adapted to mapping of human muscle, joint and bone interactions for performing clinical gait analysis of persons having neuromuscular, musculoskeletal, or neurological impairments.

27. The apparatus as claimed in Claim 24, adapted to mapping and analysis of human body motion for improving performance in sports.

28. The apparatus as claimed in Claim 24, adapted to mapping human body motion for evaluation of human interaction with military equipment.

29. The apparatus as claimed in Claim 24, adapted to tracking body motion of humans and animals for implementing realistic animation in film and television entertainment.

30. A propagated signal comprising:

an unmodulated carrier wave (40); said unmodulated carrier wave (40) being emitted sequentially from a plurality of energy sources (14) and received by a plurality of receiving means (18) for receiving and processing said propagated signal;

said unmodulated carrier wave (40) being switched between each of said plurality of energy sources (14) in a known sequence; and

said unmodulated carrier wave (40) being utilized by said receiving means (18) for computing a position of each of said plurality of said energy sources (14) from said unmodulated carrier wave and said known sequence of switching.

31. A propagated signal as claimed in Claim 30 in which

said carrier wave (40) is encoded with a plurality of codes; each one of said plurality of codes being associated with each one of said plurality of energy sources (14); and

said codes uniquely identifying said associated one of said plurality of energy sources (14) and enabling said receiving means (18) to separate and simultaneously track said propagated signal (40) received from each one of said plurality of energy sources (14).